APPENDIX C
EVALUATION OF HUMAN HEALTH EFFECTS FROM NORMAL OPERATIONS

C.1 INTRODUCTION

This appendix provides a brief general discussion on radiation and its associated health effects and describes the method and assumptions used for estimating the potential impacts and risks to individuals and the general public from exposure to the releases of radioactivity and hazardous chemicals during normal operations at the proposed reactor facilities. This information is intended to present the assessment of impacts from normal operation during tritium production in the proposed reactors, as described in Chapter 5 of this environmental impact statement (EIS). Information regarding potential radiological impacts resulting from facility accidents is provided in Appendix D of this EIS.

This appendix presents numerical information using engineering and/or scientific notation. For example, the number 100,000 can also be expressed as 1×10^5. The fraction 0.00001 can also be expressed as 1×10^{-5}. The following chart defines the equivalent numerical notations that may be used in this appendix.

FRACTIONS AND MULTIPLES OF UNITS

Multiple	*Decimal Equivalent*	*Prefix*	*Symbol*
1×10^6	1,000,000	mega-	M
1×10^3	1,000	kilo-	k
1×10^2	100	hecto-	h
1×10	10	deka-	da
1×10^{-1}	0.1	deci-	d
1×10^{-2}	0.01	centi-	c
1×10^{-3}	0.001	milli-	m
1×10^{-6}	0.000001	micro-	μ
1×10^{-9}	0.000000001	nano-	n
1×10^{-12}	0.000000000001	pico-	p
1×10^{-15}	0.000000000000001	femto-	f
1×10^{-18}	0.000000000000000001	atto-	a

C.2 RADIOLOGICAL IMPACTS ON HUMAN HEALTH

Radiation exposure and its consequences are topics of interest to the general public. For this reason, this EIS places much emphasis on the consequences of exposure to radiation, provides the reader with background information on the nature of radiation, and explains the basic concepts used in the evaluation of radiation health effects. In addition, this section provides a brief description of the characteristics of tritium and its potential health effects.

C.2.1 Background Information

C.2.1.1 Nature of Radiation and Its Effects on Humans

What Is Radiation?

Radiation is energy transferred in the form of particles or waves. Globally, human beings are exposed constantly to radiation from the solar system and from the earth's rocks and soil. This radiation contributes to the natural background radiation that always surrounds us. Manmade sources of radiation also exist, including medical and dental x-rays, household smoke detectors, and materials released from nuclear and coal-fired power plants.

All matter in the universe is composed of atoms. Radiation comes from the activity of tiny particles within an atom. As stated earlier in Appendix A, an atom consists of a positively charged nucleus (central part of an atom) with a number of negatively charged electron particles in various orbits around the nucleus. There are two types of particles in the nucleus: neutrons that are electrically neutral and protons that are positively charged. Atoms of different types are known as elements. There are more than 100 natural and manmade elements. An element has equal numbers of electrons and protons. When atoms of an element differ in their number of neutrons, they are called isotopes of that element. All elements have three or more isotopes, some or all of which could be unstable (i.e., decay with time). For example, tritium (also known as hydrogen-3) has two neutrons and is an unstable isotope of hydrogen, which has no neutrons.

Unstable isotopes undergo spontaneous change, known as radioactive disintegration or radioactive decay. The process of continuously undergoing spontaneous disintegration is called radioactivity. The radioactivity of a material decreases with time. The time it takes a material to lose half of its original radioactivity is its half-life. An isotope's half-life is a measure of its decay rate. For example, an isotope with a half-life of eight days will lose one-half of its radioactivity in that amount of time. In eight more days, one-half of the remaining radioactivity will be lost, and so on. Each radioactive element has a characteristic half-life. The half-lives of various radioactive elements may vary from millionths of a second to millions of years.

As unstable isotopes change into more stable forms, they emit electrically charged particles. These particles may be either an alpha particle (a helium nucleus) or a beta particle (an electron), with various levels of kinetic energy. Sometimes these particles are emitted in conjunction with gamma rays. The alpha and beta particles are frequently referred to as ionizing radiation. Ionizing radiation refers to the fact that the charged particle energy force can ionize, or electrically charge, an atom by stripping off one of its electrons. Gamma rays, even though they do not carry an electric charge as they pass through an element, can ionize its atoms by ejecting electrons. Thus, they cause ionization indirectly. Ionizing radiation can cause a change in the chemical composition of many things, including living tissue (organs), which can affect the way they function.

When a radioactive isotope of an element emits a particle, it changes to an entirely different element, one that may or may not be radioactive. Eventually, a stable element is formed. This transformation, which may take several steps, is known as a decay chain. For example, radium, which is a member of the radioactive decay chain of uranium, has a half-life of 1,622 years. It emits an alpha particle and becomes radon, a radioactive gas with a half-life of only 3.8 days. Radon decays first to polonium, then through a series of further decay steps to bismuth, and ultimately to lead, which is a stable element. Meanwhile, the decay products will build up and will eventually die away as time progresses.

The characteristics of various forms of ionizing radiation are briefly described below and in the box at right (see Glossary for further definition):

Radiation Type	Typical Travel Distance in Air	Barrier
α	Couple of centimeters	Sheet of paper or skin's surface
β	Few meters	Thin sheet of aluminum foil or glass
γ	Very Large [a]	Thick wall of concrete, lead, or steel
n	Very Large	Water, paraffin, graphite

[a] *Would be infinite in a vacuum*

Alpha (α)

Alpha particles are the heaviest type of ionizing radiation. They can travel only a couple centimeters in air. Alpha particles lose their energy almost as soon as they collide with anything. They can be stopped easily by a sheet of paper or by the skin's surface.

Beta (β)

Beta particles are much (7,330 times) lighter than alpha particles. They can travel a longer distance than alpha particles in the air. A high energy beta particle can travel a few meters in the air. Beta particles can pass through a sheet of paper, but may be stopped by a thin sheet of aluminum foil or glass. Tritium emits a very low energy beta particle.

Gamma (γ)

Gamma rays (and x-rays), unlike alpha or beta particles, are waves of pure energy. Gamma rays travel at the speed of light. Gamma radiation is very penetrating and requires a thick wall of concrete, lead, or steel to stop it.

Neutrons (n)

Neutrons are particles that contribute to radiation exposure both directly and indirectly. The most prolific source of neutrons is a nuclear reactor. Indirect radiation exposure occurs when gamma rays and alpha particles are emitted following neutron capture in matter. A neutron has about one quarter the weight of an alpha particle. It will travel in the air until it is absorbed in another element.

Units of Radiation Measure

During the early days of radiological experience, there was no precise unit of radiation measure. Therefore, a variety of units were used to measure radiation. These units were used to determine the amount, type, and intensity of radiation. Just as heat can be measured in terms of its intensity or effects using units of calories or degrees, amounts of radiation or its effects can be measured in units of Curies, radiation absorbed dose (rad), or dose equivalent (rem). The following summarizes those units (see also the definition in the Glossary).

Curie

The Curie, named after the French scientists Marie and Pierre Curie, describes the "intensity" of a sample of radioactive material. The rate of decay of 1 gram of radium is the basis of this unit of measure. It is equal to 3.7×10^{10} disintegrations (decays) per second.

Rad

The rad is the unit of measurement for the physical absorption of radiation. The total energy absorbed per unit quantity of tissue is referred to as absorbed dose (or simply dose). As sunlight heats pavement by giving up an amount of energy to it, radiation similarly gives up rads of energy to objects in its path. One rad is equal to the amount of radiation that leads to the deposition of 0.01 Joule of energy per kilogram of absorbing material.

Radiation Units and Conversions to International System of Units

1 Curie = 3.7×10^{10} Becquerel
1 rad = 0.01 Gray
1 rem = 0.01 Sievert
1 Gray = 1 Joule/kilogram
1 Becquerel = 1 disintegration per second

Rem

A rem is a measurement of the dose equivalent from radiation based on its biological effects. The rem is used in measuring the effects of radiation on the body as degrees Centigrade are used in measuring the effects of sunlight heating pavement. Thus, 1 rem of one type of radiation is presumed to have the same biological effects as 1 rem of any other kind of radiation. This allows comparison of the biological effects of radionuclides that emit different types of radiation.

The units of radiation measure in the International Systems of Units are: Becquerel (a measure of source intensity [activity]), Gray (a measure of absorbed dose), and Sievert (a measure of dose equivalent).

An individual may be exposed to ionizing radiation externally (from a radioactive source outside the body) or internally (from ingesting or inhaling radioactive material). The external dose is different from the internal dose because an external dose is delivered only during the actual time of exposure to the external radiation source, but an internal dose continues to be delivered as long as the radioactive source is in the body. The dose from internal exposure is calculated over 50 years following the initial exposure; both radioactive decay and elimination of the radionuclide by ordinary metabolic processes decrease the dose rate with the passage of time.

Sources of Radiation

The average American receives a total of approximately 364 millirem per year from all sources of radiation, both natural and manmade, of which approximately 300 millirem per year are from natural sources (NCRP 1987b). The sources of radiation can be divided into six different categories: (1) cosmic radiation, (2) terrestrial radiation, (3) internal radiation, (4) consumer products, (5) medical diagnosis and therapy, and (6) other sources (NCRP 1987b). These categories are discussed in the following paragraphs.

Cosmic Radiation

Cosmic radiation is ionizing radiation resulting from energetic charged particles from space continuously hitting the earth's atmosphere. These particles and the secondary particles and photons they create comprise cosmic radiation. Because the atmosphere provides some shielding against cosmic radiation, the intensity of this radiation increases with the altitude above sea level. The average dose to people in the United States from this source is approximately 27 millirem per year.

External Terrestrial Radiation

External terrestrial radiation is the radiation emitted from the radioactive materials in the Earth's rocks and soils. The average dose from external terrestrial radiation is approximately 28 millirem per year.

Internal Radiation

Internal radiation results from the human body metabolizing natural radioactive material that has entered the body by inhalation or ingestion. Natural radionuclides in the body include isotopes of uranium, thorium, radium, radon, polonium, bismuth, potassium, rubidium, and carbon. The major contributor to the annual dose equivalent for internal radioactivity are the short-lived decay products of radon, which contribute approximately 200 millirem per year. The average dose from other internal radionuclides is approximately 39 millirem per year.

Consumer Products

Consumer products also contain sources of ionizing radiation. In some products, such as smoke detectors and airport x-ray machines, the radiation source is essential to the products' operation. In other products, such as televisions and tobacco, the radiation occurs as the product's function. The average dose from consumer products is approximately 10 millirem per year.

Medical Diagnosis and Therapy

Radiation is an important diagnostic medical tool and cancer treatment. Diagnostic x-rays result in an average exposure of 39 millirem per year. Nuclear medical procedures result in an average exposure of 14 millirem per year.

Other Sources

There are a few additional sources of radiation that contribute minor doses to individuals in the United States. The dose from nuclear fuel cycle facilities (e.g., uranium mines, mills, and fuel processing plants), nuclear power plants, and transportation routes has been estimated to be less than 1 millirem per year. Radioactive fallout from atmospheric atomic bomb tests, emissions of radioactive material from nuclear facilities, emissions from certain mineral extraction facilities, and transportation of radioactive materials contribute less than 1 millirem per year to the average dose to an individual. Air travel contributes approximately 1 millirem per year to the average dose.

Exposure Pathways

As stated earlier, an individual may be exposed to ionizing radiation both externally and internally. The different ways that could result in radiation exposure to an individual are called exposure pathways. Each type of exposure is discussed separately in the following paragraphs.

External Exposure

External exposure can result from several different pathways, all having in common the fact that the radiation causing the exposure is external to the body. These pathways include exposure to a cloud of radiation passing over the receptor (e.g., an individual member of the public) standing on ground that is contaminated with radioactivity and swimming or boating in contaminated water. If the receptor departs from the source of radiation exposure, the dose rate will be reduced. It is assumed that external exposure occurs uniformly during the year. The appropriate measure of dose is called the effective dose equivalent.

Internal Exposure

Internal exposure results from a radiation source entering the human body through either inhalation of contaminated air or ingestion of contaminated food and water. In contrast to external exposure, once a

radiation source enters the body, it remains there for a period of time that varies depending on decay and biological half-life. The absorbed dose to each organ of the body is calculated for a period 50 years following the intake. The dose equivalent of this absorbed dose is called the committed dose equivalent. Various organs have different susceptibilities to harm from radiation. The quantity that takes these different susceptibilities into account is called the committed effective dose equivalent, and it provides a broad indicator of the risk to the health of an individual from radiation. The committed effective dose equivalent is a weighted sum of the committed dose equivalent in each major organ or tissue. The concept of committed effective dose equivalent applies only to internal pathways.

Radiation Protection Guides

Various organizations have issued radiation protection guides. The responsibilities of the main radiation safety organizations, particularly those that affect policies in the United States, are summarized.

International Commission on Radiological Protection

This commission has the responsibility for providing guidance in matters of radiation safety. The operating policy of this organization is to prepare recommendations to deal with basic principles of radiation protection and to leave to the various national protection committees the responsibility of introducing the detailed technical regulations, recommendations, or codes of practice best suited to the needs of their countries.

National Council on Radiation Protection and Measurements

In the United States, this council is the national organization that has the responsibility to adapt and provide detailed technical guidelines for implementing the International Commission on Radiological Protection recommendations. The organization consists of technical experts who are specialists in radiation protection and scientists who are experts in disciplines that form the basis for radiation protection.

National Research Council/National Academy of Sciences

The National Research Council is an organization within the National Academy of Sciences that associates the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the Federal Government.

Limits of Radiation Exposure

Limits of exposure to members of the public and radiation workers are based on International Commission on Radiological Protection recommendations. Each regulatory organization adopts the International Commission on Radiological Protection's recommendations and sets specific annual exposure limits (usually less than those specified by the commission). For nuclear facilities, annual exposure limits to the public are provided by the U.S. Nuclear Regulatory Commission (NRC) in 10 CFR 20, and 10 CFR 50, Appendix I. For accidents of unlikely probability of occurrence, (a likelihood of between 1-in-100 to 1-in-10,000 years), 10 CFR 100 provides the maximum exposure to the public residing at the site boundary. The dose limits for radiation workers are provided in 10 CFR 20. The U.S. Department of Energy (DOE) also has established a set of limits for radiation workers in 10 CFR 835. **Table C–1** provides the various exposure limits set by the NRC, DOE, and the U.S. Environmental Protection Agency (EPA) for radiation workers and members of the public.

Table C–1 Exposure Limits for Members of the Public and Radiation Workers

Guidance Criteria (Organization)	*Public Exposure Limits at the Site Boundary*	*Worker Exposure Limits*
Normal Operations		
10 CFR 20 (NRC)	100[a] millirem per year, all pathways	5,000 millirem per year
10 CFR 50, Appendix I (NRC)[b]	5 millirem per year, air (external); 3 millirem per year, liquid (total body) 15 millirem per year, air (maximum organ) 10 millirem per year, liquid (maximum organ)	-
40 CFR 190 (EPA)	25 millirem per year, all pathways	-
10 CFR 835 (DOE)[c]	-	5,000 millirem per year
DOE Order 5400.5 (DOE)[c]	10 millirem per year (all air pathways) 4 millirem per year (drinking water pathway) 100 millirem per year (all pathways)	-
40 CFR 61 (EPA)	10 millirem per year (all air pathways)	-
Facility Accidents		
10 CFR 100.11 (NRC)[d]	25 rem (total body dose from gamma and beta) 300 rem (thyroid inhalation dose)	-

[a] An NRC licensee may apply for prior NRC authorization to operate up to an annual dose limit of 500 millirem for an individual member of the public.
[b] Design objectives for equipment to control releases of radioactive materials in effluents from nuclear power reactors.
[c] The nuclear facilities are regulated by the NRC. DOE exposure limits are only included for comparison purposes.
[d] This guidance criteria is used to determine the exclusion area and low population zone for a nuclear power plant site.

C.2.1.2 Health Effects

Radiation exposure and its consequences are topics of interest to the general public. To provide the background for discussions of impacts, this section explains the basic concepts used in the evaluation of radiation effects.

Radiation can cause a variety of damaging health effects in people. The most significant effects are induced cancer fatalities. These effects are referred to as "latent" cancer fatalities because the cancer may take many years to develop. In the discussions that follow, all fatal cancers are considered latent; therefore, the term "latent" is not used.

The National Research Council's Committee on the Biological Effects of Ionizing Radiation (BEIR) has prepared a series of reports to advise the U.S. Government on the health consequences of radiation exposures. *Health Effects of Exposure to Low Levels of Ionizing Radiation*, BEIR V, (NAS 1990), provides the most current estimates for excess mortality from leukemia and cancers other than leukemia that are expected to result from exposure to ionizing radiation. BEIR V provides estimates that are consistently higher than those in its predecessor, BEIR III. This increase is attributed to several factors, including the use of a linear dose response model for cancers other than leukemia, revised dosimetry for the Japanese atomic bomb survivors, and additional follow-up studies of the atomic bomb survivors and other cohorts. BEIR III employs constant, relative, and absolute risk models, with separate coefficients for each of several sex and age-at-exposure groups. BEIR V develops models in which the excess relative risk is expressed as a function of age at exposure, time after exposure, and sex for each of several cancer categories. The BEIR III models were based on the assumption that absolute risks are comparable between the atomic bomb survivors and the U.S.

population. BEIR V models were based on the assumption that the relative risks are comparable. For a disease such as lung cancer, where baseline risks in the United States are much larger than those in Japan, the BEIR V approach leads to larger risk estimates than the BEIR III approach.

The models and risk coefficients in BEIR V were derived through analyses of relevant epidemiologic data that included the Japanese atomic bomb survivors, ankylosis spondylitis patients, Canadian and Massachusetts fluoroscopy (breast cancer) patients, New York postpartum mastitis (breast cancer) patients, Israeli tinea capitis (thyroid cancer) patients, and Rochester thymus (thyroid cancer) patients. Models for leukemia, respiratory cancer, digestive cancer, and other cancers used only the atomic bomb survivor data, although results of analyses of the ankylosis spondylitis patients were considered. Atomic bomb survivor analyses were based on revised dosimetry, with an assumed relative biological effectiveness of 20 for neutrons, and were restricted to doses less than 400 rads. Estimates of risks of fatal cancers other than leukemia were obtained by totaling the estimates for breast cancer, respiratory cancer, digestive cancer, and other cancers.

The National Council on Radiation Protection and Measurements (NCRP 1993), based on the radiation risk estimates provided in BEIR V and the International Commission on Radiological Protection Publication 60 recommendations (ICRP 1991), has estimated the total detriment resulting from low dose[1] or low dose rate exposure to ionizing radiation to be 0.00073 per rem for the general population and 0.00056 per rem for the working population. The total detriment includes fatal and nonfatal cancer and severe hereditary (genetic) effects. The major contribution to the total detriment is from fatal cancer and is estimated to be 0.0004 and 0.0005 per rem for the radiation workers and the general population, respectively. **Table C–2** provides the breakdown of the risk factors for both the workers and the general population.

Table C–2 Nominal Health Effects Coefficients (Risk Factors) from Ionizing Radiation

Exposed Population	*Fatal Cancer* [a,c]	*Nonfatal Cancer* [b]	*Genetic Disorders* [b]	*Total*
Working Population	0.0004	0.00008	0.00008	0.00056
General Population	0.0005	0.0001	0.00013	0.00073

[a] For fatal cancer, the health effect coefficient is the same as the probability coefficient.

[b] In determining a means of assessing health effects from radiation exposure, the International Commission on Radiological Protection has developed a weighting method for nonfatal cancers and genetic effects. Genetic effects only can be applied to a population, not individuals.

[c] For high individual exposures (greater than or equal to 20 rem), the health factors are multiplied by a factor of 2.

Source: NCRP 1993.

The numerical estimates of cancer fatalities presented in this EIS were obtained using a linear extrapolation from the nominal risk estimated for lifetime total cancer mortality, which is 0.1 Gray (10 rad). Other methods of extrapolation to the low-dose region could yield higher or lower numerical estimates of cancer fatalities. Studies of human populations exposed to low doses are inadequate to demonstrate the actual level of risk. There is scientific uncertainty about cancer risk in the low-dose region below the range of epidemiologic observation, and the possibility of no risk cannot be excluded (CIRRPC 1992).

[1] *The low dose is defined as the dose level where DNA repair can occur in a few hours after irradiation-induced damage. Currently, a dose level of about 0.2 Grays (20 rad), or a dose rate of 0.1 milligrays (0.01 rad) per minute is considered to allow the DNA to repair itself in a short period (EPA 1994).*

Health Effect Risk Factors Used in This EIS

Health impacts from radiation exposure, whether from sources external or internal to the body, generally are identified as "somatic" (i.e., affecting the exposed individual) or "genetic" (i.e., affecting descendants of the exposed individual). Radiation is more likely to produce somatic effects than genetic effects. The somatic risks of most importance are induced cancers. Except for leukemia, which can have an induction period (time between exposure to carcinogen and cancer diagnosis) of as little as 2 to 7 years, most cancers have an induction period of more than 20 years.

For a uniform irradiation of the body, the incidence of cancer varies among organs and tissues; the thyroid and skin demonstrate a greater sensitivity than other organs. Such cancers, however, also produce relatively low mortality rates because they are relatively amenable to medical treatment. Because of the readily available data for cancer mortality rates and the relative scarcity of prospective epidemiologic studies, somatic effects leading to cancer fatalities rather than cancer incidence are presented in this EIS. The numbers of cancer fatalities can be used to compare the risks among the various alternatives.

Based on the preceding discussion and the values presented in Table C–2, the fatal cancers to the general public during normal operations and for accidents in which individual doses are less than 20 rem are calculated using a health risk factor of 0.0005 per person-rem. For workers, a risk factor of 0.0004 excess fatal cancer per person-rem is used. This lower value reflects the absence of children (who are more radiosensitive than adults) in the workforce. Nonfatal cancer and genetic disorders among the public are 20 and 26 percent, respectively, of the fatal cancer risk factor. For workers, the health risk estimators are both 20 percent of the fatal cancer risk factor. These factors are not used in this EIS.

The risk factors are used to calculate the statistical expectation of the effects of exposing a population to radiation. For example, in a population of 100,000 people exposed only to natural background radiation (300 millirem per year), it is expected that about 15 latent cancer fatalities per year of exposure would result from this radiation (100,000 persons × 0.3 rem per year × 0.0005 latent cancer fatalities per person-rem = 15 latent cancer fatalities per year).

Calculations of the number of excess cancer fatalities associated with radiation exposure do not always yield whole numbers; calculations may yield numbers less than 1.0, especially in environmental impact applications. For example, if a population of 100,000 were exposed to a total dose of only 0.001 rem per person, the collective dose would be 100 person-rem, and the corresponding estimated number of latent cancer fatalities would be 0.05 (100,000 persons × 0.001 rem × 0.0005 latent cancer fatalities per person-rem = 0.05 latent cancer fatalities). The latent cancer fatality of 0.05 is the *expected* number of deaths that would result if the same exposure situation were applied to many different groups of 100,000 people. In most groups, no person (0 people) would incur a latent cancer fatality from the 0.001 rem dose each member would have received. In a small fraction of the groups, 1 latent cancer fatality would result; in exceptionally few groups, 2 or more latent cancer fatalities would occur. The *average* expected number of deaths over all the groups would be 0.05 latent cancer fatalities (just as the average of 0, 0, 0, and 1 is 1/4, or 0.25). The most likely outcome is 0 latent cancer fatalities.

These same concepts apply to estimating the effects of radiation exposure on a single individual. Consider the effects, for example, of exposure to background radiation over a lifetime. The "number of latent cancer fatalities" corresponding to a single individual's exposure over a (presumed) 72-year lifetime to 0.3 rem per year is 0.011 latent cancer fatalities (1 person × 0.3 rem per year × 72 year × 0.0005 latent cancer fatalities/person-rem = 0.011 latent cancer fatalities).

Again, this is a statistical estimate. That is, the estimated effect of background radiation exposure on the exposed individual would produce a 1.1 percent chance that the individual might incur a latent cancer fatality

caused by the exposure over his full lifetime. Presented another way, this method estimates that approximately 1.1 percent of the population might die of cancers induced by background radiation.

C.2.2 Tritium Characteristics and Biological Properties

C.2.2.1 Tritium Characteristics

Ordinary hydrogen (also called protium), deuterium, and tritium are the three isotopes of hydrogen. Tritium is the only one of the three isotopes that is radioactive. The nucleus of a hydrogen atom contains one proton, a positively charged particle. Around this nucleus orbits a single electron, a negatively charged particle that has a significantly smaller mass than the proton. Ordinary hydrogen, comprising over 99.9 percent of all naturally occurring hydrogen, has one proton and no neutrons. The nucleus of a deuterium atom contains one proton and one neutron. Deuterium comprises approximately 0.015 percent of all hydrogen. The nucleus of the tritium atom contains one proton and two neutrons. Tritium makes up only 1×10^{-18} percent of natural hydrogen. The chemical symbol for hydrogen is H. When designating the different isotopes, the isotopic number is added to the symbol so that protium becomes H^1, deuterium H^2, and tritium H^3. Deuterium and tritium are also represented as D and T, respectively.

In the radioactive decay of tritium, the nucleus emits a beta particle, a negatively charged particle similar to an electron. Upon emission of the beta particle the tritium atom is transformed into a helium atom, helium-3, with two protons and one neutron. Tritium has a half-life of approximately 12.3 years. Any amount of tritium will be reduced by 10 percent in 2 years, 25 percent in 5 years, 50 percent in 12.3 years, and 90 percent in 42 years.

As stated earlier, the emitted beta particle is a form of ionizing radiation. It will interact with the atoms and molecules in the environment around the tritium atom, ionizing atoms by removing electrons from their orbit. The beta particles emitted from a decaying tritium atom are relatively low energy particles and can be stopped by a sheet of paper or skin. Therefore, health effects on humans may result from ingestion (either eating or drinking), inhalation, or skin absorption of tritium. External exposure to tritium does not pose a significant health risk.

Because tritium undergoes radioactive decay, it must be constantly created through either natural or manmade processes. Natural sources of tritium result from the interaction of cosmic radiation and gases in the upper atmosphere. Nuclear power reactors are one manmade source for producing tritium. In a reactor core, lithium can be transformed into tritium via neutron capture. The lithium atom, with three protons and three neutrons, and the captured neutron combine to form a lithium atom with three protons and four neutrons that will instantaneously split to form an atom of tritium (one proton and two neutrons) and an atom of helium (helium-4, with two protons and two neutrons).

The following information on the biological impact of tritium is taken from the *Primer on Tritium Safe Handling Practices* (DOE 1994).

C.2.2.2 Biological Properties of Tritium

At most tritium facilities, the most commonly encountered forms of tritium are tritium gas and tritium oxide, also called “tritiated water.” Other forms of tritium may be present, such as metal tritides, tritiated pump oil, and tritiated gases like methane and ammonia. Deuterated and tritiated compounds generally have the same chemical properties as their protium counterparts, although some minor isotopic differences in reaction rates exist. These various tritiated compounds have a wide range of metabolic properties in humans under similar exposure conditions. For example, inhaled tritium gas is only slightly incorporated into the body during exposure, and the remainder is rapidly removed by exhalation following the exposure. On the other hand,

tritiated water vapor is readily taken up and retained in the body water. This discussion is limited to the effects of tritium gas and tritium oxide, the two compounds with the potential to have the most significant impact on workers and the public.

Metabolism of Gaseous Tritium

During a brief exposure to tritium gas, the gas would be inhaled and a small amount would be dissolved in the bloodstream. The dissolved gas would circulate in the bloodstream before being exhaled along with the gaseous waste products (carbon dioxide) and normal water vapor. If the exposure persists, the gas will reach other body fluids. A small percentage of the gaseous tritium would be converted to tritium oxide, most likely by oxidation in the gastrointestinal tract. Early experiments involving human exposure to a concentration of 9 microcuries per milliliter resulted in an increase in the tritium oxide concentration in urine of 7.7×10^{-3} microcuries per milliliter per hour of exposure. Although independent of the breathing rate, this conversion can be expressed as the ratio of the tritium oxide buildup to the tritium inhaled as tritium gas at a nominal breathing rate (20 liters per minute). In this context, the conversion is 0.003 percent of the total gaseous tritium inhaled. More recent experiments with six volunteers resulted in a conversion of 0.005 percent. For gaseous tritium exposures, there are two doses: (1) a lung dose from the tritium in the air inside the lung, and (2) a whole body dose from the tritium gas that has been converted to tritium oxide. The tritiated water converted from the gas in the body behaves as an exposure to tritiated water. Intake of gaseous tritium through the skin has been found to have negligible effects compared with those from inhalation. Small amounts of tritium can enter the skin through unprotected contact with contaminated metal surfaces, which results in organically bound tritium in skin and in urine.

Metabolism of Tritiated Water

The biological incorporation (uptake) of airborne tritium oxide can be extremely efficient—up to 99 percent of inhaled tritium oxide would be taken into the body by the circulating blood. Ingested liquid tritium oxide also would be almost completely absorbed by the gastrointestinal tract and would appear quickly in the bloodstream. Within minutes, it would be found in varying concentrations in the organs, fluids, and tissues of the body. Skin absorption of airborne tritium oxide also is important, especially during hot weather, because of the normal movement of water through the skin. For skin temperatures between 30 and 40°C (86 to 104°F), the absorption of tritium oxide is about 50 percent of that for tritium oxide by inhalation (assuming an average breathing rate associated with light work of 20 liters per minute). No matter how it is absorbed, the tritium oxide would be uniformly distributed in all biological fluids within one to two hours. In addition, a small fraction of the tritium would be incorporated into easily exchanged hydrogen sites in organic molecules. Hence, retention of tritiated water can be described as the sum of several terms: (1) shorter-term retention time associated with the tritium oxide that characteristically behaves like body water, and (2) longer-term retention time that represents the tritium incorporated in body organs.

Biological Half-Life of Tritium Oxide (Tritiated Water)

Biological half-life is a measure of how long tritium would remain in the human body. Studies of biological elimination rates of body water in humans date back to 1934, when the body water turnover rate was measured using deuteriated water, a water molecule containing deuterium (H^2). Since that time, several additional studies have been conducted with deuteriated water and tritiated water. A simple average of the data suggests a value of 9.5 days for the measured biological half-life of water in the body with a deviation of ±50 percent.

Calculations based on total fluid intake indicate a similar value. This is reasonable because the turnover rate of tritiated water should be identical to that of body water. In order words, the biological half-life of tritium is a function of the average daily throughput of water. The biological half-life of tritium oxide has been studied when outdoor temperatures varied at the time of tritium uptake. The data suggest that biological half-

lives are shorter in warmer months (a measured 7.5-day half-life in an environment with a mean outdoor temperature of 27°C (~81°F) in contrast to an average measured 9.5-day half-life in an environment with a mean outdoor temperature of 17°C (~63°F)). Such findings are consistent with metabolic pathways involving sensible and insensible perspiration. As such, the skin absorption and perspiration pathways can become an important part of body water exchange routes. It is important to note that a person who is perspiring will have a greater absorption of tritium from contact with tritiated surfaces.

Prolonged exposures can be expected to affect the biological half-life. This results from the longer-term components of the retention of tritium in the body. Tritium's interaction with organic hydrogen can result in additional half-life components ranging from 21 to 320 days and 250 to 550 days. The shorter duration indicates that organic molecules in the body retain tritium relatively briefly. The longer duration indicates long-term retention by other compounds in the body that do not readily exchange hydrogen or that metabolize more slowly. However, the overall contribution from organically bound tritium is relatively small—less than about 5 percent for acute exposures and about 10 percent for chronic exposures. Methods used to compute the annual limits on intake of air and water specify only the body water component and include the assumption of a 10-day biological half-life, as mentioned above.

Bioassay and Internal Dosimetry

Exposure to tritium oxide is by far the most important type of tritium exposure. The tritium oxide enters the body by inhalation or skin absorption. When immersed in tritiated water vapor, the body takes in approximately twice as much tritium through the lungs as through the skin. Once in the body, it is circulated by the blood stream and finds its way into fluids both inside and outside the cells.

According to the International Commission on Radiological Protection (ICRP 1980), the derived air concentration for tritium gas and tritium oxide are 540,000 microcuries per cubic meter and 21.6 microcuries per cubic meter, respectively. The derived air concentration is defined as that concentration of a gas which, if a worker were exposed to it for one working year (2,000 hours), would result in an annual dose of 5 rem. The ratio of these derived air concentrations (25,000) is based on a lung exposure from the gas and a whole body exposure from the oxide. However, as noted earlier, when a person is exposed to tritium gas in the air, an additional dose actually results—one to the whole body. During exposure to tritium gas, a small fraction of the tritium exchanges in the lungs and is transferred by the blood to the gastrointestinal tract where it is oxidized by enzymes. This process results in a buildup of tritium oxide until the tritium gas is removed by exhalation at the end of the exposure. The resultant dose from exposure to this tritium oxide is roughly comparable to the lung dose from exposure to tritium gas. Thus, the total effective dose from a tritium gas exposure is about 10,000 times less than the total effective dose from an equal exposure to airborne tritium oxide.

C.2.2.3 Genetic Effects of Tritium

As stated earlier, tritium moves readily through the bloodstream after uptake in the body. The low energy of tritium beta particle emissions limits its range in tissue and results in a unique radiation dose pattern. The potential genetic hazard of tritium has been studied in a variety of systems using both prokaryotes[2] and eukaryotes[2]. This research, presented at the Workshop on Tritium Radiobiology and Health Physics, has been summarized in the National Council on Radiation Protection and Measurements Report No. 63 (NCRP 1979). A review of these studies, as given in the National Council on Radiation Protection and Measurements Report No. 89 (NCRP 1987a), concluded that, although transmutational effects exist in both whole animals and *in vitro* cell systems, their effects in the whole animal relative to the effect from a beta particle dose from tritium are small and should receive minor consideration in estimating genetic risks from tritium.

[2]*Organisms with one or more cells that have a visible, evident nucleus.*

Additional studies were performed as a result of: (1) allegations of links between tritium releases and deaths from congenital anomalies around Canada's Pickering Nuclear Generating Station and (2) concerns about excess cancers from tritium releases during a 1960's detonation in an underground salt dome in Lamar County, Mississippi.

In the first study (AECB 1991), conducted for the Atomic Energy Control Board of Canada, the analysis did not support the hypothesis of increased rates of stillbirths, neonatal mortality, increased prevalence of birth defects, or significant correlation between tritium release and Down's Syndrome. In the second study (Richter and Stockwell 1998), conducted by the DOE Office of Epidemiological Studies, the investigators found no association between cancer mortality and distance from the center of detonation.

C.3 METHODOLOGY FOR ESTIMATING RADIOLOGICAL IMPACTS

The radiological impacts from normal operation of the reactor facilities were calculated using Version 1.485 of the GENII computer code (PNL 1988). Site-specific input data were used, including location, meteorology, population, food production and consumption, and source terms. Section C.3.1 briefly describes GENII and outlines the approach used for normal operations.

C.3.1 GENII Computer Code

The GENII computer model, developed by Pacific Northwest National Laboratory, is an integrated system of various computer modules that analyze environmental contamination resulting from acute or chronic releases to, or initial contamination in, air, water, or soil. The model calculates radiation doses to individuals and populations. The GENII computer model is well documented for assumptions, technical approach, method, and quality assurance issues (PNL 1988). The GENII computer model has gone through extensive quality assurance and quality control steps, including comparing results from model computations with those from hand calculations and performing internal and external peer reviews. Recommendations given in these reports were incorporated into the final GENII computer model, as appropriate.

For this EIS, only the ENVIN, ENV, and DOSE computer modules were used. The codes are connected through data transfer files. The output of one code is stored in a file that can be used by the next code in the system. The functions of the three GENII computer modules used in this EIS are discussed below.

ENVIN

The ENVIN module of the GENII code controls the reading of input files and organizes the input for optimal use in the environmental transport and exposure module, ENV. The ENVIN code interprets the basic input, reads the basic GENII data libraries and other optional input files, and organizes the input into sequential segments based on radionuclide decay chains.

A standardized file that contains scenario, control, and inventory parameters is used as input to ENVIN. Radionuclide inventories can be entered as functions of releases to air or water, concentrations in basic environmental media (air, soil, or water), or concentrations in foods. If certain atmospheric dispersion options have been selected, this module can generate tables of atmospheric dispersion parameters that will be used in later calculations. If the finite plume air submersion option is requested in addition to the atmospheric dispersion calculations, preliminary energy-dependent finite plume dose factors can be prepared as well. The ENVIN module prepares the data transfer files that are used as input by the ENV module; ENVIN generates the first portion of the calculation documentation—the run input parameters report.

ENV

The ENV module calculates the environmental transfer, uptake, and human exposure to radionuclides that result from the chosen scenario for the user-specified source term. The code reads the input files from ENVIN and then, for each radionuclide chain, sequentially performs the precalculations to establish the conditions at the start of the exposure scenario. Environmental concentrations of radionuclides are established at the beginning of the scenario by assuming decay of preexisting sources, considering biotic transport of existing subsurface contamination, and defining soil contamination from continuing atmospheric or irrigation depositions. For each year of postulated exposure, the code then estimates the air, surface soil, deep soil, groundwater, and surface water concentrations of each radionuclide in the chain. Human exposures and intakes of each radionuclide are calculated for: (1) pathways of external exposure from finite atmospheric plumes; (2) inhalation; (3) external exposure from contaminated soil, sediments, and water; (4) external exposure from special geometries; and (5) internal exposures from consumption of terrestrial foods, aquatic foods, drinking water, animal products, and inadvertent intake of soil. The intermediate information on annual media concentrations and intake rates are written to data transfer files. Although these may be accessed directly, they are usually used as input to the DOSE module of GENII.

DOSE

The DOSE module reads the intake and exposure rates defined by the ENV module and converts the data to radiation dose.

C.3.2 Data and General Assumptions

To perform the dose assessments for this EIS, different types of data were collected and generated. In addition, calculational assumptions were made. This section discusses the data collected and generated (SAIC 1998) for use in performing the dose assessments and the assumptions made for this EIS.

Meteorological Data

The meteorological data used for all normal operational scenarios discussed in this EIS were in the form of joint frequency data files. A joint frequency data file is a table listing the fractions of time the wind blows in a certain direction, at a certain speed, and within a certain stability class. The joint frequency data files were based on measurements taken over a period of several years at different locations and heights at each of the sites. Average annual meteorological conditions (averaged over the measurement period) as given in the plant's final safety analysis reports were used for normal operation.

Population Data

Population distributions were based on the *1990 Census of Population and Housing* data (DOC 1992). Projections were determined for the year 2025 (approximate midlife of operations) for areas within 80 kilometers (50 miles) of the release location at the three candidate reactor sites. The site population in 2025, assumed to be representative of the population over the operational period evaluated, was used in the impact assessments. The population was spatially distributed on a circular grid with 16 directions and 10 radial distances up to 80 kilometers (50 miles). The grid was centered at the precise location from which the radionuclides were assumed to be released.

Source Term Data

The tritium-producing burnable absorber rod (TPBAR) source terms (i.e., quantities of tritium [in the form of tritium oxide] released to the environment over a given period) were estimated based on anticipated TPBAR

characteristic releases. The source terms used to generate the estimated incremental impacts of normal operations are provided in Section C.3.4 for each of the three candidate reactor sites evaluated in this EIS.

Food Production and Consumption Data

Data from the *1992 Census of Agriculture* (DOC 1993) were used to generate site-specific data for food production. Food production was spatially distributed on the same circular grid used for the population distributions. The consumption rates used in GENII were those for the maximum individual and the average individual. People living within the 80-kilometer (50-mile) assessment area were assumed to consume only food grown in that area.

Calculational Assumptions

Dose assessments were performed for both members of the general public and workers for each reactor site examined in this EIS. These assessments were made to determine the incremental doses that would be associated with the tritium production alternatives addressed in this EIS. Incremental doses for members of the public were calculated (via GENII) for two different types of receptors:

- Maximally Exposed Offsite Individual—The maximally exposed individual was assumed to be located at a position on the site boundary that would yield the highest impacts during normal operations of a given alternative.

- Population—The general population living within 80 kilometers (50 miles) of the facility in the year 2025.

To estimate radiological impacts from normal operations, the following additional assumptions and factors were considered in using GENII:

- Radiological gaseous emissions were assumed to be released to the atmosphere through the plant stack; for Watts Bar 1, Sequoyah 1, or Sequoyah 2, the stack height is 40 meters (131 feet), and for Bellefonte 1 or Bellefonte 2, it is 83 meters (272 feet).

- Ground surfaces were assumed to have no previous deposition of radionuclides.

- The annual external exposure time to the plume and to soil contamination was 0.7 years (16.8 hours per day) for the maximally exposed offsite individual (NRC 1977b).

- The annual external exposure time to the plume and to soil contamination was 0.5 years (12 hours per day) for the population (NRC 1977b).

- The inhalation exposure time to the plume was 1.0 years for the maximally exposed individual and general population.

- The exposed individual or population was assumed to have the characteristics and habits (e.g., inhalation and ingestion rates) of an adult human.

- A semi-infinite/finite plume model was used for air immersion doses. Other pathways evaluated were ground exposure; inhalation; ingestion of food crops and animal products contaminated by either deposition of radioactivity from the air or irrigation; ingestion of fish and other aquatic food raised in contaminated water; swimming and boating in contaminated surface water; and drinking contaminated water. All applicable pathways (e.g., inhalation, drinking water, external exposure) were analyzed at each of the three reactor site locations.

- Reported release heights were used for atmospheric releases and were assumed to be the effective stack height. The resultant doses were conservative, as use of the actual stack height negates plume rise.

- The calculated doses were 50-year committed doses from 1 year of intake.

- Average volumetric river flow rates (measured locally downstream of each site; see Table C–6) were used.

- Individual annual exposure times to swimming, boating, and shoreline recreation were taken from site environmental reports and NRC Regulatory Guide 1.109, as appropriate (TVA 1997, NRC 1995, TVA 1974a, TVA 1974b, NRC 1977b).

- For conservatism, a transit time of zero was assumed for releases to reach aquatic recreation areas.

- The year 2025 drinking water population was estimated by applying the same growth factor as given for the entire 80-kilometer (50-mile) radius population within each respective plant's final environmental statement (NRC 1995, AEC 1974, TVA 1974a). The estimated fish-eating population in year 2025 was conservatively assumed to equal the drinking water population.

- Drinking water treatment was assumed, with a holdup (transit) time of 0.5 days for the Watts Bar and Sequoyah Nuclear Plants and 0.2 days for the Bellefonte Nuclear Plant.

- Annual drinking water quantities for the average and maximally exposed individual were referenced from NRC Regulatory Guide 1.109 (NRC 1977b).

- Fish consumption data were referenced from NRC Regulatory Guide 1.109 (NRC 1977b).

The exposure, uptake, and usage parameters used in the GENII model for normal operations are provided in **Tables C–3, C–4, C–5**, and **C–6**.

Table C–3 GENII Exposure Parameters to Plumes and Soil Contamination (Normal Operations)

Maximally Exposed Offsite Individual				***General Population***			
External Exposure		***Inhalation of Plume***		***External Exposure***		***Inhalation of Plume***	
Plume (hours)	***Soil Contaminatio n (hours)***	***Exposure Time (hours)***	***Breathing Rate (cubic centimeters per second)***	***Plume (hours)***	***Soil Contamination (hours)***	***Exposure Time (hours)***	***Breathing Rate (cubic centimeters per second)***
6,136	6,136	8,766	270	4,383	4,383	8,766	270

Source: PNL 1988.

Table C–4 GENII Usage Parameters for Consumption of Terrestrial Food

Food Type	Maximally Exposed Offsite Individual				General Population			
	Growing Time (days)	Yield (kilograms per square meter)	Holdup Time (days)	Consumption Rate (kilograms per year)	Growing Time (days)	Yield (kilograms per square meter)	Holdup Time (days)	Consumption Rate (kilograms per year)
Leafy Vegetables	90.0	1.5	1.0	30.0	90.0	1.5	14.0	15.0
Root Vegetables	90.0	4.0	5.0	220.0	90.0	4.0	14.0	140.0
Fruit	90.0	2.0	5.0	330.0	90.0	2.0	14.0	64.0
Grains/Cereals	90.0	0.8	180.0	80.0	90.0	0.8	180.0	72.0

Source: PNL 1988.

Table C–5 GENII Usage Parameters for Consumption of Animal Products

Food Type	Human Consumption Rate (kilograms per year)	Holdup Time (days)	Animal Stored Feed				Animal Fresh Forage			
			Diet Fraction	Growing Time (days)	Yield (kilograms per square meter)	Storage Time (days)	Diet Fraction	Growing Time (days)	Yield (kilograms per square meter)	Storage Time (days)
Maximally Exposed Offsite Individual										
Beef	80.0	15.0	0.25	90.0	0.80	180.0	0.75	45.0	2.00	100.0
Poultry	18.0	1.0	1.00	90.0	0.80	180.0	–	–	–	–
Milk	270.0	1.0	0.25	45.0	2.00	100.0	0.75	30.0	1.50	0.00
Eggs	30.0	1.0	1.00	90.0	0.80	180.0	–	–	–	–
General Population										
Beef	70.0	34.0	0.25	90.0	0.80	180.0	0.75	45.0	2.00	100.0
Poultry	8.5	34.0	1.0	90.0	0.80	180.0	–	–	–	–
Milk	230.0	3.0	0.25	45.0	2.00	100.0	0.75	30.0	1.50	0.00
Eggs	20.0	18.0	1.0	90.0	0.80	180.0	–	–	–	–

Source: PNL 1988.

Incremental worker doses associated with tritium production activities were determined from historical data associated with similar operations (TVA 1998b). Very small incremental doses to reactor facility workers may result from refueling outage activities and increased resin bed handling. Estimated baseline and incremental worker doses at the reactor sites are supplied in referenced data reports (TVA 1998a, NRC 1997). Worker doses are provided in Section 5 of this EIS.

Table C–6 GENII Liquid Pathway Parameters

Parameter	*Plant*		
	Sequoyah	***Watts Bar***	***Bellefonte***
Average river volumetric flow rate (cubic meters per second)	850	940	1,100
Swimming exposure time per year (hours)	918 – Maximum 22 – Average	918 – Maximum 22 – Average	918 – Maximum 22 – Average
Boating exposure time per year (hours)	1,500 – Maximum 104 – Average	1,500 – Maximum 104 – Average	1,500 – Maximum 104 – Average
River shoreline exposure time per year (hours)	500–Maximum 8.3–Average	500–Maximum 8.3–Average	500–Maximum 8.3–Average
Transit time for releases to reach aquatic recreation	0	0	0
Year 2025 population ingesting drinking water and fish	524,000	274,000	230,000
Drinking water holdup time (days)	0.5	0.5	0.2[a]
Drinking water consumption rate (liters per year)	730–Maximum 370–Average	730–Maximum 370–Average	730–Maximum 370–Average
Fish Consumption Rate (pounds per year)	45–Maximum 15.2–Average	45–Maximum 15.2–Average	45–Maximum 15.2–Average

[a] This value is calculated based on average river water velocity and the distance between the plant discharge location to water treatment plant (TVA 1974a).

Sources: NRC 1995, NRC 1977a, AEC 1974, TVA 1974a, TVA 1974b, TVA 1997, TVA 1991, TVA 1995, TVA 1996.

C.3.3 Uncertainties

The sequence of analyses performed to generate the radiological impact estimates from normal operation include: (1) selection of normal operational modes, (2) estimation of source terms, (3) estimation of environmental transport and uptake of radionuclides, (4) calculation of radiation doses to exposed individuals, and (5) estimation of health effects. There are uncertainties associated with each of these steps. Uncertainties exist in the way the physical systems being analyzed are represented by the computational models and in the data required to exercise the models (due to measurement, sampling, or natural variability).

In principle, one can estimate the uncertainty associated with each source and predict the remaining uncertainty in the results of each set of calculations. Thus, one can propagate the uncertainties from one set of calculations to the next and estimate the uncertainty in the final results. However, conducting such a full-scale quantitative uncertainty analysis is neither practical nor a standard practice for a study of this type. Instead, the analysis is designed to ensure—through judicious selection of release scenarios, models, and parameters—that the results represent the potential risks. This is accomplished by making conservative assumptions in the calculations at each step. The models, parameters, and release scenarios used in the calculations are selected in such a way that most intermediate results and, consequently, the final estimates of impacts, are greater than would be expected. As a result, even though the range of uncertainty in a quantity might be large, the value calculated for the quantity would be close to one of the extremes in the range of possible values, so the chance of the actual quantity being greater than the calculated value would be low (or the chance of the quantity being less than the calculated value if the criteria are such that the quantity has to be maximized). The goal of the radiological assessment for normal operation in this study has been to produce results that are conservative.

The degree of conservatism in the calculated results is closely related to the range of possible values the quantity can have. This range is determined by what can be expected to realistically occur. Thus, the only processes considered are those that are credible for the conditions under which the physical system being modeled operates. This consideration has been employed for the normal operation analyses.

Although the radionuclide composition of source terms are reasonable estimates, there are uncertainties in the radionuclide inventory and release reactions that affect estimated impacts.

C.3.4 Radiological Releases to the Environment and Associated Impact

The NRC has assessed the potential radiation doses to individuals and surrounding populations that could result from the operation of the Watts Bar, Sequoyah, and Bellefonte Nuclear Plants in the related facilities' Final Environmental Statements (NRC 1995, AEC 1974, TVA 1974a). To assess the potential radiation dose to the individual and population from the operation of these plants in a tritium-producing mode, this EIS uses the results in those statements and superimposes the doses that would result from additional releases of tritium. The dose assessment uses the method prescribed by the NRC in Regulatory Guides 1.109 (NRC 1977b), 1.111 (NRC 1977a), and 4.2 (NRC 1976), with the adjustments as needed.

Radiological Releases to the Environment

Normal operational radiological assessments were determined (modeled) for two tritium production scenarios at each candidate reactor site: (1) production of tritium via the loading of 1,000 TPBARs into a reactor core, and (2) production of tritium via the loading of a maximum number of TPBARs into a reactor core. The maximum number of TPBARs that can be loaded in each reactor varies among the three candidate sites. For calculational purposes in this EIS, the maximum number of TPBARs was assumed to be 3,400.

During tritium production, some tritium is expected to permeate through the TPBARs, leading to an increase in the quantity of tritium in the reactor's coolant water system. Any tritium that is released from the TPBARs during normal plant operation enters the reactor coolant system and is distributed throughout the reactor coolant, chemical volume control, liquid radwaste, and gaseous radwaste systems. The rate of this accumulation depends on the coolant system capacities and water volume exchanges associated with the plant's required water chemistry and soluble boron adjustments. The tritium released into the reactor coolant system is processed along with the rest of the coolant, and this evolution provides the avenue for the transport and release of tritium outside the reactor coolant system. For the purposes of the analysis, the design tritium permeation per TPBAR, on average, is assumed to be 1 Curie per year (PNNL 1997, PNNL 1999). The anticipated increases in tritium releases (in Curies) to both the atmosphere (air emission) and the water pathways (liquid effluent) as a result of this design permeation rate are shown in **Table C-7.** These values are based on the assumption that about 90 percent of the tritium in the reactor coolant system would be released in the liquid effluent and 10 percent would be released to the atmosphere as tritiated water vapor (air emissions).

Table C–7 Annual Increase in Tritium Releases to the Environment at Each Site

	1,000 TPBARs Irradiation		***3,400 TPBARs Irradiation***	
	Air Emissions	***Liquid Effluents***	***Air Emissions***	***Liquid Effluents***
Tritium Releases (Curies)	100	900	340	3,060

The design of the TPBARs and the required TPBAR cladding quality assurance essentially preclude the potential for TPBAR failure during irradiation. For the purposes of analyses in this EIS, even though it is unlikely to occur, it was assumed that during a 40-year operation two TPBARs could fail in an operating cycle and release all the tritium generated in the failed TPBARs to the reactor coolant system. The potential increases in tritium releases (in Curies) from the two failed TPBARs to both the air emissions and the liquid effluents over an 18-month operating cycle are shown in **Table C-8.** These values represent the additional releases over that of the normal operation given in Table C-7, and are based on the following assumptions:

- Each TPBAR would generate a maximum design limit of 1.2 grams of tritium over an 18-month operating cycle; the specific activity of tritium is 9,640 Curies per gram (CRC 1982).
- Two failed TPBARs could release a total of about 23,150 Curies of tritium to the reactor coolant system. The design maximum of 1.2 grams of tritium per rod could be released to the reactor coolant system.
- About 90 percent of the tritium in the reactor coolant system would be released in the liquid effluents and 10 percent would be released to the atmosphere.

Table C–8 Increases in Tritium Releases to the Environment from Two Failed TPBARs in an 18-Month Operating Cycle

	Air Emissions	***Liquid Effluents***
Tritium Releases (Curies)	2,315	20,835

The current radioactivity releases in the air emissions and the liquid effluents from normal operation (with zero TPBARs) at Watts Bar 1 and Sequoyah 1 or Sequoyah 2 are given in **Tables C-9** and **C-10.** The estimated radioactivity releases during tritium production at Watts Bar and Sequoyah would be the sum of the values given in these tables and those given in Table C-7. For the Bellefonte Nuclear Plant, it is assumed that the releases would be similar to those of Watts Bar.

Table C–9 Average (1996-1997) Annual Radioactivity Releases to the Air and Liquid at Watts Bar 1

Isotopes[a]	***Air Emissions (Curies)***	***Liquid Effluents (Curies)***
Tritium releases	5.6	639
Other radioactive releases:	283	1.32
Argon-41	1.0	-
Krypton-85	2.4	-
Krypton-85m	0.06	-
Xenon-131m	3.2	-
Xenon-133	271	-
Xenon-133m	1.2	-
Xenon-135	3.9	-
Chromium-51	-	0.14
Cobalt-58	-	0.42
Cobalt-60	-	0.020
Iron-55	-	0.12
Iron-59	-	0.096
Rubidium-88	-	0.012
Antimony-124	-	0.077

Isotopes[a]	*Air Emissions (Curies)*	*Liquid Effluents (Curies)*
Antimony-125	-	0.10
Antimony-126	-	0.12
Iodine-131	-	0.017
Cesium-134	-	0.050
Cesium-137	-	0.088
Total Releases	288.6	640.3

[a] Only isotopes with values greater than 0.01 were listed in this table.
Source: TVA 1999.

Table C–10 Average (1995-1997) Annual Radioactivity Releases to the Air and Liquid at Sequoyah 1 or Sequoyah 2

Isotopes[a]	*Air Emissions (Curies)*	*Liquid Effluents (Curies)*
Tritium releases	25	714
Other radioactive releases:	120	1.15
Argon-41	0.95	-
Krypton-85	0.32	-
Krypton-85m	0.090	-
Krypton-88	0.068	-
Xenon-131m	1.9	-
Xenon-133	113	-
Xenon-133m	1.5	-
Xenon-135	1.9	-
Xenon-135m	0.032	-
Chromium-51		0.035
Cobalt-58	-	0.65
Cobalt-60	-	0.11
Iron-55	-	0.14
Manganese-54	-	0.014
Niobium-95	-	0.014
Antimony-125	-	0.053
Cesium-134	-	0.03
Cesium-137	-	0.046
Total Releases	145	715.2

[a] Only isotopes with values greater than 0.01 were listed in this table.
Source: TVA 1999.

Radiological Impacts

As stated earlier, doses to members of the public from tritium releases during normal operations were calculated using GENII code (PNL 1988). GENII uses "special" transport assumptions in its evaluation of the tritiated water movement through various food chains. The concentration of tritium in each food type is assumed to have the same specific activity as the contaminating medium (PNL 1988). The assumption is approximately valid for situations involving continuous replenishment of tritium in the medium and represents a conservative approximation for residual tritium in soil (NRC 1994). When soil is contaminated with residual tritium and no tritium from air and water is continually added to the soil, the contamination would be expected

to rapidly escape (by evaporation) from the soil or plants that had taken up this tritium. GENII, however, conservatively assumes that the soil tritium is retained and remains available for plant uptake over time.

As a result, the effective dose associated with the ingestion pathway calculated by GENII is very conservative. The calculated ingestion dose is between 80 to 95 percent of the total body dose. In addition, the assumption that people living within 80 kilometers (50 miles) of each site would eat all the contaminated food produced within that area makes the dose calculations even more conservative. Even with this overestimation, all calculated doses resulting from tritium releases during normal operation are within the limits set forth for the operation of each reactor (see **Tables C–11, C–12, and C–13**). Tables C–11, C–12, and C–13 present potential radiological impacts to two individual receptor groups that may be exposed to releases associated with incident-free operation and the abnormal event of two TPBAR failures in a given 18-month fuel cycle for each of the three candidate sites. These two groups are the maximally exposed member of the public and the population living within 80 kilometers (50 miles) of each of the sites in the year 2025. Each table presents the estimated doses from gaseous emissions (air) and liquid effluents (liquid) under the No Action Alternative (current plant conditions), and the estimated incremental doses from tritium releases to air and liquid resulting from 1,000 and 3,400 TPBAR irradiations in each reactor. For Watts Bar and Sequoyah, actual air and liquid doses included in their 1997 operation year environmental reports were used for the No Action Alternative (operation with 0 TPBARs). For Bellefonte, since the plant is not yet operational, the estimated dose values given in the final environmental statement (AEC 1974) were used for the plant operation with 0 TPBARs. The air doses provided in the final environmental statement include external exposure due to gamma rays and beta particles emanating from the gaseous radioactive emissions and thyroid organ dose due to inhalation and ingestion of contaminated air and food (milk), respectively. GENII calculates air doses by considering both the external exposure and the internal exposure to all organs and provides the total effective dose equivalent. Therefore, the results presented in the plant final environmental statements were adjusted (i.e., the organ dose was presented in terms of equivalent whole body dose to enable combination with the external dose) before being added to the incremental doses resulting from tritium releases. The No Action liquid doses given in the plant final environmental statements are the total body doses; therefore, no adjustments were needed.

The following text summarizes the calculated doses presented for the two public groups:

No Action

- The maximally exposed offsite individual doses from air releases were taken directly from plant environmental reports for Watts Bar and Sequoyah (TVA 1998a) and from the final environmental statement for Bellefonte (AEC 1974). For Bellefonte, the dose value given for the external air immersion "total body dose" was added to the maximum thyroid organ dose that accounts for exposures via inhalation and ingestion pathways. The thyroid dose was multiplied by the International Commission on Radiological Protection 26 weighting factor of 0.03 (PNL 1988) to get a "weighted committed dose equivalent" prior to being added to the external air immersion dose.

- Liquid doses to the maximally exposed offsite individual were directly cited from the referenced reports (TVA 1998a, AEC 1974).

- Population doses from air releases were cited directly from the referenced reports (TVA 1998a, AEC 1974) and subsequently were adjusted for the projected population in the year 2025 by applying the demographic growth factors presented in the EIS.

- Population dose from liquid releases were cited from the referenced reports and also were adjusted for the projected population in the year 2025.

Tritium Production:

- Incremental doses from tritium releases under incident-free operation (per air and liquid pathways), calculated for 1,000 and 3,400 TPBARs via the method described in Sections C.3.1 and C.3.2, are presented in Tables C–11 through C–13.

- Total doses (No Action doses + Incremental doses) from incident-free operation under tritium production, presented separately for the air and the liquid releases and then combined to demonstrate regulatory compliance with the applicable standards shown in Table C–1, are presented in Tables C–11 through C–13.

- Incremental doses from tritium release from the abnormal event of two TPBAR failures in a given 18-month fuel cycle are presented in **Table C–14.**

C.4 IMPACTS OF EXPOSURES TO HAZARDOUS CHEMICALS ON HUMAN HEALTH

The potential impacts of exposure to hazardous chemicals released to the atmosphere as a result of tritium production were evaluated for the routine operation of the reactor facilities.

The receptors considered in these evaluations are the maximally exposed individual and the offsite population living within an 80-kilometer (50-mile) radius of the facilities. Impacts of exposures to hazardous chemicals for workers directly involved in reactor operation and tritium production were not quantitatively evaluated because the use of personal protective equipment and engineering process controls would limit their exposure to levels within applicable Occupational Safety and Health Administration Permissible Exposure Limits or American Conference of Governmental Industrial Hygienists Threshold Limit Values.

As a result of releases from the routine operation of the reactor facilities, receptors are expected to be potentially exposed to concentrations of hazardous chemicals that are below those that could cause acutely toxic health effects. Acutely toxic health effects generally result from short-term exposure to relatively high concentrations of contaminants, such as those that may be encountered during facility accidents. Long-term exposure to relatively lower concentrations of hazardous chemicals can produce adverse chronic health effects that include both carcinogenic and noncarcinogenic effects. The health effect endpoints evaluated in this analysis include excess incidences of latent cancers for carcinogenic chemicals and a spectrum of chemical-specific noncancer health effects (e.g., headaches, membrane irritation, neurotoxicity, immunotoxicity, liver toxicity, kidney toxicity, developmental toxicity, reproductive toxicity, and genetic toxicity) for noncarcinogens.

Methodology

Estimates of airborne concentrations of hazardous chemicals were developed using ISC3 air dispersion model (EPA 1995). This model was developed by the U.S. Environmental Protection Agency (EPA) for regulatory air dispersion modeling applications. ISC3 is the most recent version of the model and is approved for use for a wide variety of emission sources and conditions. The ISC3 model estimates atmospheric concentrations based on the airborne emissions from the processing facility for each block in a circular grid comprised of 16 directional sectors (e.g., north, north-northeast, northeast) at radial distances out to 80 kilometers (50 miles) from the point of release, producing a distribution of atmospheric concentrations. The maximally exposed offsite individual is located in the block with the highest estimated concentration. The short-term version of the model (ISCST3) was used to estimate potential exposures to offsite populations.

Table C–11 Annual Radiological Impacts to the Public from Incident-Free Tritium Production Operations at Watts Bar 1

	No Action		*Incremental Dose For 1,000 TPBARs*		*Operation with 1,000 TPBARs*			*Incremental Dose for 3,400 TPBARs*		*Operation with 3,400 TPBARs*		
Receptors	***Air***	***Liquid***	***Air***	***Liquid***	***Air***	***Liquid***	***Total***	***Air***	***Liquid***	***Air***	***Liquid***	***Total***
Maximally Exposed Offsite Individual												
Dose (millirem)	0.036	0.25	0.012	0.0014	0.048	0.25	0.30	0.042	0.0050	0.078	0.26	0.34
Fatal Cancer Risk	1.8×10^{-8}	1.3×10^{-7}	6.0×10^{-9}	7.0×10^{-10}	2.4×10^{-8}	1.3×10^{-7}	1.5×10^{-7}	2.1×10^{-8}	2.5×10^{-9}	3.9×10^{-8}	1.3×10^{-7}	1.7×10^{-7}
Population Dose Within 80 Kilometers (50 Miles) for Year 2025												
Dose (person-rem)	0.071	0.48	0.15	0.19	0.22	0.67	0.89	0.50	0.69	0.57	1.2	1.8
Fatal Cancers	0.000036	0.00024	0.000075	0.000095	0.00011	0.00034	0.00045	0.00025	0.00035	0.00029	0.00060	0.00090

Source: TVA 1998a.
Note: The values given in this table are rounded up to two significant figures.

Table C–12 Annual Radiological Impacts to the Public from Incident-Free Tritium Production Operations at Sequoyah 1 or Sequoyah 2

	No Action		*Incremental Dose For 1,000 TPBARs*		*Operation with 1,000 TPBARs*			*Incremental Dose for 3,400 TPBARs*		*Operation with 3,400 TPBARs*		
Receptors	***Air***	***Liquid***	***Air***	***Liquid***	***Air***	***Liquid***	***Total***	***Air***	***Liquid***	***Air***	***Liquid***	***Total***
Maximally Exposed Offsite Individual												
Dose (millirem)	0.031	0.022	0.015	0.0016	0.046	0.024	0.070	0.052	0.0054	0.083	0.027	0.11
Fatal Cancer Risk	1.6×10^{-8}	1.1×10^{-8}	7.5×10^{-9}	8.0×10^{-10}	2.3×10^{-8}	1.2×10^{-8}	3.5×10^{-8}	2.6×10^{-8}	2.7×10^{-9}	4.2×10^{-8}	1.4×10^{-8}	5.6×10^{-8}
Population Dose Within 80 Kilometers (50 Miles) for Year 2025												
Dose (person-rem)	0.49	1.1	0.16	0.41	0.65	1.5	2.2	0.54	1.4	1.0	2.5	3.5
Fatal Cancers	0.00025	0.00055	0.000080	0.00021	0.00033	0.00075	0.0011	0.00027	0.00070	0.00050	0.0013	0.0018

Source: TVA 1998a.
Note: The values given in this table are rounded up to two significant figures.

Table C–13 Annual Radiological Impacts to the Public from Incident-Free Tritium Production Operations at Bellefonte 1

	No Action		*Incremental Dose For 1,000 TPBARs*		*Operation with 1,000 TPBARs*			*Incremental Dose for 3,400 TPBARs*		*Operation with 3,400 TPBARs*		
Receptors	***Air***	***Liquid***	***Air***	***Liquid***	***Air***	***Liquid***	***Total***	***Air***	***Liquid***	***Air***	***Liquid***	***Total***
Maximally Exposed Offsite Individual												
Dose (millirem)	0[a]	0[a]	0.0020	0.0012	0.25[c]	0.013[c]	0.26	0.0065	0.0042	0.26[c]	0.016[c]	0.28
Fatal Cancer Risk	0	0	1.0×10^{-9}	6.0×10^{-10}	1.3×10^{-7}	6.5×10^{-9}	1.3×10^{-7}	3.3×10^{-9}	2.1×10^{-9}	1.3×10^{-7}	8.0×10^{-9}	1.4×10^{-7}
Population Dose Within 80 Kilometers (50 Miles) for Year 2025												
Dose (person-rem)	0[b]	0[b]	0.13	0.14	0.40[c]	1.2[c]	1.6	0.44	0.47	0.71[c]	1.6[c]	2.3
Fatal Cancers	0	0	0.000065	0.000070	0.00020	0.0006	0.0008	0.00022	0.00024	0.00036	0.0008	0.0012

[a, b] These no action values represent the absence of impacts associated with the nonoperational status of the Bellefonte Nuclear Plant. For a single operational Bellefonte Nuclear Plant unit (operation without tritium production activities), the impacts to the public have been estimated to be: 0.26 millirem (0.25 millirem from the air pathway and 0.012 millirem from the liquid pathway) to the maximally exposed offsite individual and 1.4 person-rem (0.27 person-rem from the air pathway and 1.1 person-rem from the liquid pathway) to the surrounding population within 80 kilometers (50 miles) in the year 2025.

[c] These values are a summation of incremental impacts attributable to TPBAR tritium releases and estimated single Bellefonte Nuclear Plant unit operational impacts.

For Bellefonte 1 and 2 operation, the potential impacts are twice the values given in this table.

Source: AEC 1974.

Note: The values given in this table are rounded up to two significant figures.

Table C–14 Radiological Impacts to the Public from the Failure of Two TPBARs at Each of the Reactor Sites

	Watts Bar 1			*Sequoyah 1 or Sequoyah 2*			*Bellefonte 1 or Bellefonte 2*		
Receptors	***Air***	***Liquid***	***Total***	***Air***	***Liquid***	***Total***	***Air***	***Liquid***	***Total***
Maximally Exposed Offsite Individual									
Dose (millirem)	0.29	0.033	0.32	0.36	0.037	0.40	0.045	0.028	0.073
Fatal Cancer Risk	1.5×10^{-7}	1.7×10^{-8}	1.6×10^{-7}	1.8×10^{-7}	1.9×10^{-8}	2.0×10^{-7}	2.3×10^{-8}	1.4×10^{-8}	3.7×10^{-8}
Population Dose Within 80 Kilometers (50 Miles) for Year 2025									
Dose (person-rem)	3.43	4.41	7.84	3.67	9.19	12.86	3.06	3.18	6.24
Risk	0.0017	0.0022	0.0039	0.0018	0.0046	0.0064	0.0015	0.0016	0.0031

This EIS estimates the noncancer health risks by comparing modeled air concentrations of contaminants produced by ISC3 to the EPA Reference Concentrations published in the Integrated Risk Information System. For each noncarcinogenic chemical, potential health risks are estimated by dividing the estimated airborne concentration by the chemical-specific Reference Concentrations value to obtain a noncancer hazard quotient:

Noncancer Hazard Quotient = air concentration/Reference Concentrations

Reference Concentrations are estimates (with an uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of harmful effects during a lifetime. Hazard Quotients are calculated for each hazardous chemical to which receptors may be exposed. Hazard Quotients for each chemical are summed to generate a Hazard Index. The Hazard Index is an estimate of the total noncancer toxicity potential from exposure to hazardous chemicals. According to EPA risk assessment guidelines (EPA 1989), if the Hazard Index value is less than or equal to 1.0, the exposure is unlikely to produce adverse toxic effects. If the Hazard Index exceeds 1.0, adverse noncancer health effects may result from the exposure.

For carcinogenic chemicals, risk is estimated by the following equation:

$$\text{Risk} = \text{CA} \times \text{URF}$$

where:

Risk = a unitless probability of cancer incidence.
CA = contaminant concentration in air (in micrograms/cubic meters).
URF = cancer inhalation unit risk factor (in units of cancers per micrograms/cubic meters).

CA is estimated by multiplying the output of the ISC3 model by the process duration to obtain estimates of total airborne exposure for each process.

Cancer unit risk factors are used in risk assessments to estimate an upper-bound lifetime probability of an individual developing cancer as a result of exposure to a particular level of a potential carcinogen.

Assumptions

The airborne pathway is assumed to be the principal exposure route by which the offsite population maximally exposed individual is exposed to hazardous chemicals released from reactor facilities. No synergistic or antagonistic effects are assumed to occur from exposure to the hazardous chemicals released from reactor facilities. Synergistic effects among released contaminants may result in adverse health effects that are greater than those estimated, whereas antagonistic effects among released chemicals may result in less severe health effects than those estimated.

Analysis

The potential impacts of exposure to hazardous chemicals released to the atmosphere during routine operations of the reactor facilities to produce tritium are presented in Chapter 5 for each alternative.

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